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HABITS OF THE SHORT-TAILED SHREW, *BLARINA BREVICAUDA* (SAY)[1]

A. FRANKLIN SHULL

INTRODUCTION.

IN January, 1906, in a low tract of land near Ann Arbor, Professor Jacob Reighard found upon the snow a number of heaps of snails of several species of the genus Polygyra (Fig. 1). At his suggestion and under his supervision I undertook to find what had heaped these shells and to pursue any further studies suggested by the discovery. I am also indebted to Mr. Bryant Walker for identifying a number of snails.

The heaps contained from two or three to more than a hundred shells. During the whole period of observation five species were found represented,— *Polygyra albolabris, P. multilineata, P. profunda, P. thyroides*, and *P. fraterna*, in the approximate ratio of 300: 250: 30: 1: 8. On several successive excursions the number of shells in individual heaps was counted, and it was found to vary; shells had either been taken away or added. No marks were visible in the snow to tell how the shells had been moved, but there was invariably the opening of a small burrow near the heap. My problem was to discover what animal was moving the snails, and also something of its habits.

FINDING THE SHREW.

The presence of a burrow at each heap and the absence of marks in the snow suggested that the occupant of the burrows was moving the shells. To determine this point, bacteria dishes were inverted over each of several of the heaps of snails together with the adjacent burrow. The snails were found to be moved just as before. A further test was made as follows: — A heavy wire was passed through a spool and bent down at the ends in the form of an inverted U. The sharpened ends of the wire were thrust into the ground. The spool was held in such a position that a thread unwound from it could easily pass into the burrow. On the reel thus formed were wound several yards of carpet thread, to the end of which a snail was tied by means of a hole pierced through its shell just back of the lip. The shell was then placed near the opening of the burrow. The thread was marked at intervals so that it would be possible, without first finding the shell, to determine how much had been reeled off. At the next visit to the heaps the thread was found extending into the burrow for about a foot. The shell was still fast to the string, but had been broken open and the snail was gone.

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[1] Contributions from the Zoological Laboratory of the University of Michigan No. 112.

Now that I knew where to look for the animal, I began to set traps. At one place there were two large heaps of shells about a meter apart, each near a burrow descending abruptly into the ground. Between these was a well worn path in the snow at the surface of the ground. Into this path a steel wire trap was sunk by digging out a bit of the earth, so that the trigger of the trap was on a level with the bottom of the trail. No bait was used. At my next visit the trap contained a short-tailed shrew, *Blarina brevicauda*. Many of the snails had been removed, showing either that the animal had for some time escaped the trap, or that another shrew had carried on the work after the first had been captured.

My work was then ordered according to the following plan: (1) To discover as many heaps of snails as possible in different situations, and to record minutely the changes in location of the shells above ground; (2) As soon as the frost had thawed out of the ground, to excavate the burrows and search for nests; (3) To capture in the meantime one or more shrews and confine them in the laboratory; and (4) To make various psychological studies in the laboratory and in the field.

Observations on the Heaps of Snail Shells.

All my field observations were made in Steere's swamp, a tract four miles south of Ann Arbor. It was here alone that the heaps of snails were found, though search was made for them at other places where the shrew had been taken. The soil of this region is rich black peat, at many places in a rather early stage of decomposition. The groundwater level in spring occurs at a depth of only 15 to 20 cm., so that after even moderate rains the water stands at the surface in places for several days. Several ditches have been dug through the swamp. Near these the groundwater level sinks gradually to the level of the water in the ditch, which was usually 60 to 70 cm. below the surface at the season when my observations were made. According to old settlers, the region was formerly occupied by tamaracks, black ash, and willows. Since it was cleared a few years ago, nettles, goldenrod, and sumac, with here and there a thicket of black ash, willows, elder, and raspberry, have taken the swamp.

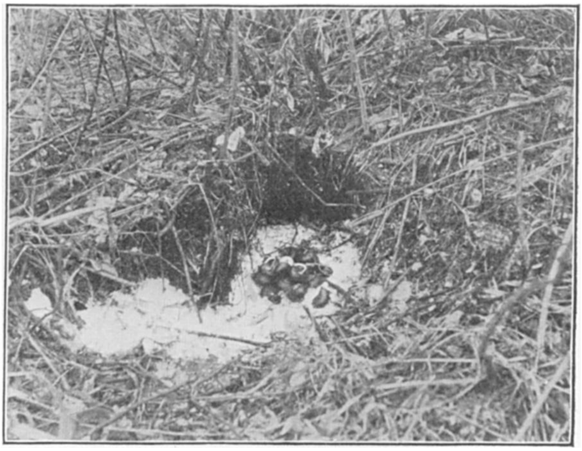

Fig. 1.— A heap of 19 snail shells near the opening of a burrow of *Blarina brevicauda*. This burrow is not visible, the large one beyond the heap belonging to another animal. The shells are in a slight depression where the snow has not melted.

Apparently the region favors the growth of snails, for they are abundant. Many live ones were found after warm weather had set in, and large numbers of empty shells were scattered over the surface. Within two areas containing the principal thickets and goldenrod patches of the swamp, each less than 150 meters in radius, there were found, by careful search, a total of over forty heaps of shells. The larger portion of these was being moved. Of those shells that were not being moved, a number were cracked.

They may have been broken before the shrews began collecting them; they may have been accidentally cracked in transportation; or the shrews may have broken them purposely, to render the snails immobile. This effect was produced by compressing some snails in a vise until their shells were cracked much like those in the field. These snails were placed with uninjured ones on moist earth in a warm situation; the latter were soon crawling about. Those with broken shells never came out although for three weeks they contracted in response to thrusts with a stick, showing that they were still alive.

The shells at the various heaps were either occupied or empty. The number of both sorts was being increased in certain heaps which were receiving additions. When, at another time, shells were being removed from these heaps, only the number of occupied shells was diminished, whereas that of the empty shells remained the same. To determine whether this distinction occurred regularly, a considerable portion of the shells was numbered. The figures were placed near the base of the columella, since in all the broken shells that had been observed up to that time this portion remained intact. At each visit, the numbers of the shells at individual heaps were recorded, and when they were not too numerous, their relative position was carefully mapped. A record was kept of the condition of the shells, whether they were occupied or empty, entire or broken, at the time of numbering. As new shells were added to the heaps, they were numbered.

From Feb. 15 to Apr. 7, 144 shells found in the field were numbered. Of these, 99 were occupied, and 45 were empty, most of the latter being unbroken. To increase the number under observation, 25 snails that had been killed in formalin and then transferred to alcohol were added to the various heaps where the number of shells was found to vary. At the end of this period of more than seven weeks, the records showed that the following disposition had been made of the shells:

TABLE I. Showing the number of occupied and empty shells, also snails killed in formalin, which were removed from the surface, and the number left at the surface.

Condition of shells.	Number of shells.	Number of shells removed.	Number of shells left.
Occupied	99	76	23
Empty	45	2	43
Formalin	25	7	18

It is seen that most of the occupied shells were removed, although but few of the empty ones were ever taken away. The formalin snails show neither extreme, though the majority were untouched. Apparently the shrews have some method of distinguishing between an empty shell, a normally occupied one, and a snail killed in formalin. Experiments to determine the basis of this distinction are described under the head of Psychology.

The numbering of the shells served also to show the relation between the activities of the shrews and climatic conditions. The climatic data are from the Observatory of the University of Michigan. Humidity was not recorded but it seems hardly probable that the absolute humidities possible at the low temperatures that prevailed would have any marked effect. The temperature readings on days when field trips were made, and the observations on the shells for a period of seven weeks are given in Table II. The shells here included were brought to the surface of the ground at 21 different points on an area not more than 8 meters in diameter. Two shrews were eventually captured at this place, and subsequent excavation of the burrows within this area revealed but one nest. I have concluded, therefore, that the heaping up and removal of all these shells was probably the work of a single pair of shrews. My field trips were made sometimes in the forenoon, sometimes in the afternoon. I nearly always visited this small area first, since it lay on that side of the swamp nearest Ann Arbor. I then passed on to the more distant parts of the swamp, and returned to the same area some three hours later, again carefully noting the arrangement of the shells. In only one instance did I find that any shells had been moved during the three hours, and then three shells were brought to the surface in the forenoon. From these facts I have concluded that most of the shells are moved at night. In the table, therefore, I have given the minimum temperature of the night, rather than the maximum or the average. The Fahrenheit scale is retained as given in the weather records. The snails killed in formalin which were placed at the burrows in this area are not included in the counts.

Table II. Showing the number of shells at the surface in an area 8 m. in diameter, and the minimum nightly temperature, for a period of over seven weeks.

Date.	Minimum tempera-ture °F	Number of shells at surface.			Change in total number of shells since last visit.	Change in minimum temperature since last visit.
		Occupied	Empty	Total		
Feb. 15	2	61	13	74	....	....
20	30	32	17	49	— 25	+32
22	29	28	18	46	— 3	— 1
24	38	33	18	51	+ 5	+ 9
27	14	146	23	169	+118	—24
Mar. 1	23	118	24	142	— 27	+ 9
2	26	....	....	....	....	....
3	31	....	....	....	....	....
4	25	....	....	....	....	....
5	23	....	....	....	....	....
6	19	72	25	97	— 45	— 4
8	32	52	25	77	— 20	+13
10	25	59	25	84	+ 7	— 7
13	16	56	25	81	— 3	— 9
15	14	57	25	82	+ 1	— 2
20	16	60	25	85	+ 3	+ 2
24	8	59	27	86	+ 1	— 8
27	35	29	32	61	— 25	+27
31	25	26	32	58	— 3	—10
Apr. 3	35	24	32	56	— 2	+10
7	37	16	32	48	— 8	+ 2

As in Table I it is seen that the number of empty shells was never diminished, showing that once the empty shells were brought to the surface they were not ordinarily moved again. Throughout the seven weeks there is a steady increase in the number of empty shells. If the last two columns be compared, it is observed that on ten of the sixteen days the change in temperature and the change in the number of shells are of opposite sign,— that is, with a rise in temperature shells are removed and vice versa. These ten days include all the most marked temperature changes, namely, those on Feb. 20, Feb. 27, Mar. 8, and Mar. 27. Similar to these are the changes for Mar. 1 and Apr. 3. The conspicuous exceptions are Feb. 24 and Mar. 31, when, though the temperature changes are marked, the change in the number of shells is of the same sign as the temperature change. Further, with the one exception of Mar. 6, all the considerable changes in the number of shells occurred at times when the temperature changes were of opposite sign. On this date there seemed to have been a marked removal of shells into the burrows, while at the same time the temperature had fallen. However, five days had elapsed since the last preceding visit. In this time there had not been a steady decline of the temperature; but the temperature had risen 8° between Mar. 1 and Mar. 3, and then fallen 12° from Mar. 3 to Mar. 6. Had I observed the shells on Mar. 3, the number of shells might have been much smaller than for Mar. 1, and then increased to Mar. 6. This seems especially probable since some of the individual heaps showed an increase on Mar. 6, and others a decrease. The decreasing effect of the rise of temperature prevailed.

NESTS AND BURROWS

The Burrows.— The record of the snails was closed Apr. 7. Though a few occupied shells were still above ground, the weather was then so warm that several of the snails were found crawling about. Records of their transportation were untrustworthy after that time, and were discontinued. By this time the frost was in large measure out of the ground, and excavation of the burrows was begun. Two methods were employed. Where the ground was not very wet, flour was sometimes blown into the burrows with a small hand bellows. The burrow was then carefully opened as far as the walls were whitened, and more flour was blown in. If the ground were wet, the flour soon became moistened and lost much of its whiteness. A more successful method was to pass a rather stiff rubber tube into the burrow to keep it open while the spade was being used.

Some difficulty was experienced at first in determining which burrows were those of the shrew. The runs at the surface in which the shrew was trapped looked exactly like those of the meadow vole, or field mouse, *Microtus pennsylvanicus*. Moreover, I have seen Microtus enter burrows that descended abruptly into the ground, so that it could not be said with certainty that even the underground burrows were those of the shrew. Further, I have found underground nests used by Microtus, notwithstanding the emphasis which Rhoads (1903, p. 100) places on the statement that the nests of this species are built "*at the surface.*" The position of any nests that might be found could not then be used as a safe criterion. Some of the burrows had heaps of shells near them, which could serve as the criterion if it were known that Microtus never used snails for food. To determine this point, two meadow voles were confined in iron cages in the laboratory. Each was given a vessel of water, and equal care was taken to keep each cage clean and dry. One Microtus was given corn, wheat, crackers, bread crumbs, etc., the other only a few live snails. At the end of 30 hours the latter Microtus was dead, but the former lived for several days, when it was removed from the cage. Fearing that such an early death might have been due to injuries received in capture, I confined two other voles in similar cages. Each was given only water and snails. One died in 48 hours, the other in 56. Later eight voles were captured and kept in confinement for a week to insure that they had not suffered injury while being captured. They were all in excellent condition at the end of this time. They were then confined in pairs successively, one of each pair being given its common food (grains, crackers, etc.), the other

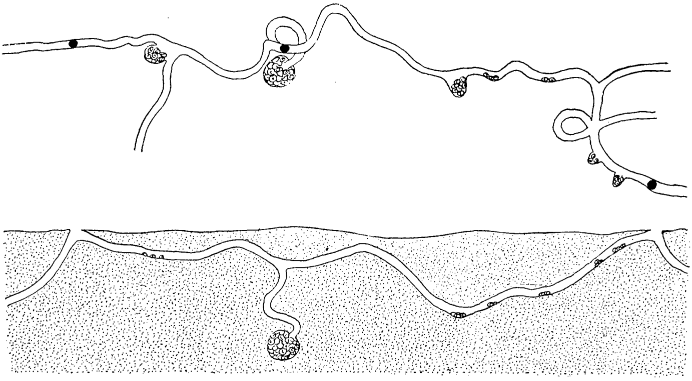

FIG. 2.— Diagram of a typical burrow of *Blarina brevicauda*, showing distribution of snail shells, and an underground storage chamber with spiral descent. The upper figure is a horizontal projection; the lower an ideal vertical section. The black circles in the upper diagram are points where the burrow descended abruptly into the ground.

only water and snails. In each case the one confined with snails died in less than 48 hours, the other remained in good condition. From these experiments I have concluded that all burrows with snail shells in or beside them were at one time used by the shrew. Taking this as the only criterion at first, I found other features later which distinguished the burrows of the two animals.

The burrows used by Blarina were usually 25 to 30 mm. in diameter. Those at the surface were exactly like those of Microtus, running in zigzag fashion under weeds and grasses, often pushing the latter aside, sometimes crushing them down, crossing and recrossing to form a complex network which in several cases was easily traced for 30 meters. When the burrows entered the ground, they did so at a steep angle, as Kennicott (1857, p. 94) has described. After descending 15 or 20 cm. they became more nearly horizontal, and passed along between 3 or 4 and 40 cm. below the surface. Branches were frequently sent off, at almost any angle. There was no ridge of earth above the burrow, even when the latter came near the surface, though Stone and Cram (1902, p. 181) mention such ridges. A typical burrow is represented in horizontal view and in ideal section in Fig. 2. Usually the burrows returned to

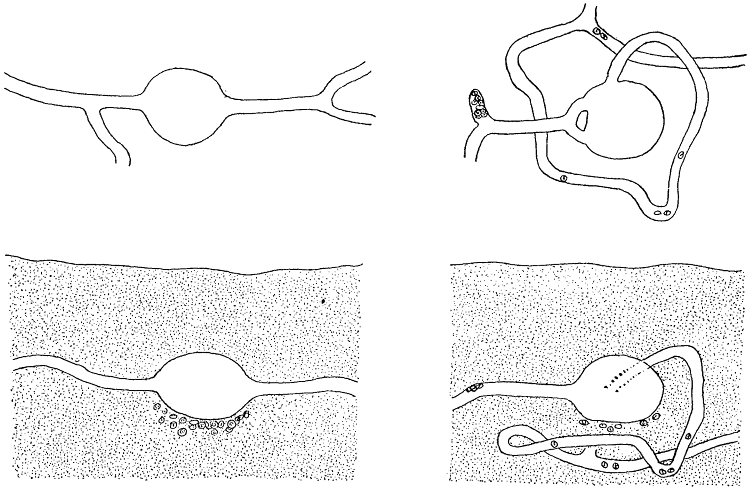

FIG. 3.— Diagrams of two nests of *Blarina brevicauda* and the burrows near them, showing distribution of snail shells. The upper figure in each case is a horizontal view; the lower an ideal vertical section.

the surface, rising as abruptly at one end as they had descended at the other. The two openings of a single burrow were never found closer together than a meter, and they were occasionally four meters apart. This fact gives another means of distinguishing the burrows of Blarina from those of Microtus. As far as I have observed, the openings of an individual underground burrow of Microtus were never as far apart as a meter, usually not more than 35 or 40 cm. Microtus burrows, moreover, were not found to extend as deep into the soil as those of Blarina.

Nests and the Burrows Near Them.— Nests are found along the course of the burrows. In digging out the burrows some sixteen nests were unearthed. Some of these were along ditch banks where the groundwater level was lower than elsewhere. All the others were in small elevations such as mounds where celery had been buried or hills thrown up by roots of fallen trees. The nests were found at depths of 15 to 40 cm. They were 12 to 15 cm. in diameter, and slightly depressed from the spherical form. They were usually made of grass, sedge, and leaves of nettle, goldenrod or ash, arranged in the form of a hollow ball, the shell of which was 1 to 3 cm. thick. One was composed entirely of hair which microscopic examination showed to be that of the meadow vole. When plant materials were used, the plants furnishing them were invariably found immediately adjoining the nest. If grass was near the nest, it was used almost to the exclusion of other leaves. Coarse materials were used without being shredded or torn into smaller pieces. This constitutes an easy distinction between the nests of Blarina and such nests of Microtus as are constructed of anything larger than grass. In all the nests of Microtus which I observed, coarse materials were torn apart; sedge leaves 6 to 8 mm. wide were shredded into three or four strips, and corn blades and leaves of trees were torn into irregular pieces of any size less than about 2 cm. When the same kinds of material were used in Blarina nests they were in no way subdivided.

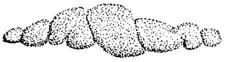
FIG. 4.— Excrement of *Blarina brevicauda.* Natural size.

Very rarely, in the vicinity of nests, the excrement of Blarina was found. In the laboratory, the excrement was piled up in the corners of the cage, but the only deposits found in the field occurred singly. The excrement was greenish black when fresh, slightly brownish when dry. It was voided in spindle-shaped portions 25 to 30 mm. long, coiled in various ways, as in Fig. 4. Very different is the excrement of Microtus, which is found in black or brown spindles only 5 to 8 mm. long.

Usually two, three, or four burrows radiated from the nest. At one nest, however, no burrows could be found. I had followed an ordinary burrow with a rubber tube until the burrow seemed to come to a blind end; the tube could be pushed no further in any direction. Another burrow running obliquely to this one was then excavated. When I had approached within about 35 cm. of the place where the first burrow had been abandoned, the second burrow also was closed. A third burrow approaching the same spot was next dug open, and it likewise ended blindly. A spade was set in at the point toward which the three burrows converged, and at the first spadeful a nest was turned out. The partly eaten body of a meadow vole near by showed that the nest was then being used, and was not a relic of the preceding year. Careful search all round the nest failed to reveal a burrow leading to it. The soft, loose soil was then carefully dug up to a distance of 40 cm. around the nest and 20 cm. below it and examined as it was thrown out to discover the shrew. None was found, so the soil was thrown back and stamped down. At my next visit a burrow opened to the surface directly over the former location of the nest, showing where the shrew had escaped. It had evidently been present when I dug up the nest, but had escaped my spade. In this case I have concluded that the shrew was obliged to force its way through the mass of loose soil for a distance of about 40 cm. every time it entered or left the nest.

At one nest, in addition to three horizontal burrows radiating from it, a fourth was traced obliquely downward from the bottom of the nest, at an angle of about 40° with the horizontal. At a distance of about 60 cm. from the nest it terminated blindly.

At all but one of the sixteen nests unearthed, snail shells were found stored beneath and at the sides of the nest. All the shells at the nests were empty at the time of excavation, between Apr. 10 and June 10. Their number varied from two or three dozen to 166. Empty shells were also scattered at irregular intervals along the burrows. Sometimes they were thrust into the soil at the sides of the burrow in groups of 2 to 10. At other places short branches led either downward or laterally from the main burrows, and then expanded into chambers filled with shells, mingled with loose soil. Such chambers contained in some cases as many as 80 shells. Generally, all the shells were empty, but one such chamber contained 69 shells, of which 54 were still occupied the last week in April. In several instances when such a chamber was located beneath the main burrow, the branch burrow leading to it was spiral in form, like a winding staircase. One of these is illustrated in Fig. 2. In two instances empty shells, broken exactly like those found elsewhere, were found inside nests which, from their composition of shredded material and position at the surface of the ground, must have been Microtus nests.

Method of Burrowing.— The method of burrowing was observed and experimented on in the laboratory, where a shrew captured by hand was kept for some time. When it was first confined, loose black soil was placed in the cage to a depth of about 10 cm. Into this soft soil the shrew at once thrust its nose, and by violent backward and outward strokes of its forefeet, forced its way through the soil like a wedge. No difficulty was experienced in burrowing 20 or 30 cm. in a minute. The movements underground were evidenced by the movement of the soil at the surface; but no ridge was formed above the burrow. When clods were encountered, they were readily moved, even if fifteen or twenty times as large as the shrew and proportionately much heavier.

During the first night a rather elaborate system of burrows opening to the surface at seven or eight points was worked out. The aggregate length of burrow was not known, as I did not dig out the soil, but it included the whole cage which measured 35 by 48 cm.

Some time later the shrew was put into another cage in which sandy soil had been placed. The same method of procedure was followed in attempting to make burrows, but small headway was made. I watched the shrew for half an hour, during which time it had not succeeded in getting under the surface. The next morning a burrow 15 cm. long open at both ends was found. At the end of a week there was an aggregate of 55 cm. of burrow with three openings. An extension of 40 cm. had been made from one of the former openings. This sandy soil had not been packed. Hence the difficulty in burrowing in it must have been due to its weight, not to its hardness. In neither the black nor sandy soil did the shrew loosen the soil with its teeth as Kennicott (1857, p. 94) has conjectured. Neither then nor at any other time during the confinement of the shrew did I observe any marked surface runs which the animal was in the habit of following. Instead, it ran about anywhere in the cage.

Food.

Dietary of Blarina.— Two articles of food of Blarina have been so far mentioned, namely, snails and voles. A fair idea of the extent to which snails are used as food may be gathered from the data presented in Table II. On Feb. 27, there were at the particular series of burrows represented in this table 146 occupied shells. On Mar. 1, one of the two shrews which were found in possession of the burrows was captured, so that the succeeding work was that of one shrew. By Apr. 7, all but 16 of these snails, that is, 130 in all, had been removed underground. When the final excavation of the burrows was made at the end of April, all these shells were empty. One shrew must, therefore, have eaten 130 snails between Mar. 1 and the last of April.

The only quantitative evidence obtained in the field in regard to the vole diet was found at the nest mentioned above as having been made exclusively of the hair of this animal. Beside this nest, thrust into the loose peat, were the bodies of two freshly killed meadow voles and that of a third half eaten. In addition to these there were several handfuls of hair in which were mixed legs and tails enough for about twenty voles. I could not know how long it had taken to accumulate this mass. The hair was still moist, but was packed so close that moisture would be retained a long time even in the dry soil in which the nest was located.

To determine more accurately the quantity of mice and other foods eaten by the shrew, experiments were made in the laboratory. A shrew was kept in confinement for over five weeks, in a wire covered cage in which earth was placed to a depth of about 10 cm. When practicable, live food was furnished. Among the various foods tried were meadow voles and house mice (*Mus musculus*), May beetles (Lachnosterna) and their grubs, moth larvae, other insects and pupae, earthworms, snails, sowbugs, carrots, crackers, roots of grasses and other plants. None of the last three articles were ever touched as food. If any article proved especially acceptable to the shrew, that food was furnished exclusively for several days, and the quantity consumed was noted. From these figures the average per day was computed. The result in each of the foods thus tested is given in Table III.

TABLE III. Showing the quantities of various foods consumed by an individual of *Blarina brevicauda* when a single article of food was furnished.

Article of food.	Number consumed.	Number of days on which this food was exclusively furnished.	Average diet per day.
Meadow voles	4	6	$\frac{2}{3}$
House mice	3	3	1
May beetles (adult)	77	5	15
May beetles (larvae)	26 *	2	13
Earthworms (4 cm. when contracted)	142	4	35

Other articles of food were furnished at other times, and some proved favorites; but owing to the difficulty in securing the food no quantitative data were secured. Other insects, such as various ground beetles, giant water bugs (Benacus), and *Hydrophilus triangularis*, were furnished. All were eaten, but the ground beetles were the favorite. Other larvae of insects besides Lachnosterna were readily taken, even the "woolly bear" of *Pyrrharctia isabella*. Sowbugs were eagerly devoured. When live food was not to be had, beef was furnished, and was eaten readily. I made only two stomach examinations. One stomach contained an insect larva mutilated beyond recognition; the other the remains of a meadow vole, recognizable by the hairs swallowed with the flesh. Vegetable foods were invariably rejected, though Professor Reighard has captured the shrew in traps baited with nut meats scented with anise oil, and the specimens taken still had fragments of the nut meats in their teeth.

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* Proved insufficient; all were consumed by 11 A. M. on second day.

Method of Capturing Food.— On several occasions I witnessed the capture of prey. In the case of the voles and the mice, the attack was essentially the same as described by Merriam (1886, pp. 166-168) and Morden (1883, p. 283). The house mouse, being very agile, was not taken in the open, but only when it entered the shrew's burrows. I observed this twice. The clumsy vole, on the other hand, was pursued above ground, cornered in the cage, and caught. In each case the shrew seized the animal's ear in its teeth. After the shrew had been dragged around the cage until its victim was almost exhausted, it quickly loosed its hold on the ear, seized the head in the parietal region, and pierced the skull with its teeth. In two cases the prey was dragged part way into a burrow after it had been killed. In the third case it was eaten at once at the surface. The brain and cranium were eaten first, then the neck and shoulders. The skin was closely cleaned and rolled back till the tail was reached. The snout, legs, skin, and tail were left.

Some difficulty was experienced in making observations on the eating of snails. When beef or mice were furnished, snails were not touched. Finally, when all other foods were excluded, snails put in the cage of a morning were devoured before the following morning, though they remained untouched during the day. Learning by this means that the shrew would eat snails at that time of year (early in June), I starved it for a day, then in order to keep it at the surface put it into a cage with sandy soil, and gave it a few snails. The snails were large and their shells were hard. The shrew put its lower jaw into the aperture in an attempt to reach the snail. Once its forefoot was thrust in. Failing to get the snail in this way, it set its teeth across the outer turn of the shell and tried to break it. This it failed to do in my presence, but later the same shells were found broken. It seems from these observations that in the case of large shells, breaking is a last resort. A group of empty shells taken from one of the underground chambers in the series of burrows in which this same captive shrew was taken is shown in Fig. 5. The group on the left contains all the unbroken shells. Those on the right were broken, being mostly small and immature shells of the same species as those on the left. These small shells were of course much more fragile than the mature ones.

From the way in which the attempt to get the snails was begun, it appears that when the shells are not broken the snails are dragged out through the aperture. I did not see this done. To determine whether it could be successfully accomplished, I seized an extended snail with a heavy forceps and pulled upon it strongly. With a steady pull the attachments to the shell slowly yielded and the snail was removed almost entire.

Psychology.

I have described reels which were set at several of the burrows to determine whether the animal that was moving the snails occupied the burrows. The same reels were used to determine how the occupied shells were distinguished from the empty ones. The possible means that suggested themselves were the weight of the snail, and the senses of touch, sight, and smell.

Muscular Sense.— To learn whether weight was the criterion, an empty shell was stuffed with sandy soil till it was about as heavy as an occupied one. This, with an empty shell and an occupied one, was placed near one of the burrows. Each shell was tied to a reel, and all were placed at equally accessible points. The occupied shell was drawn into the burrow at the time of the first decided rise of temperature, while the other two were left indefinitely. The experiment was repeated, but the occupied shell was so placed that the shrew would have to go round the empty and stuffed shells and under the reel in order to get it. The occupied shell was again removed and the other two left. The experiment was twice repeated at another burrow, with the same results. Evidently weight of shell is not the determining feature. It seemed possible that the center of gravity might not be at the same point in a stuffed shell as in an occupied one, and that the shrew could detect this difference. Therefore the position of the center of gravity in a stuffed and an occupied shell was determined by balancing on a knife edge and by suspension; it was found to be the same in the two shells.

Tactile Sense.— It might be supposed that the shrew would reach into a shell with its feet and feel whether the snail was there. I found later that the tactile sense was acute. When the shrew was running at full speed in its cage and came upon an obstacle, it invariably stopped short before touching it except with its vibrissae. The most common obstacle was its water dish, which was frequently moved about to different places in the cage. I am not certain that I ever observed the shrew run against the water dish even immediately after it had been moved. I have seen the shrew run past masses of such favorite food as earthworms without noticing them, but when a worm in its wriggling touched the tactile hairs, the shrew turned at once and seized it. To learn whether the tactile sense was used to determine the presence of a snail in its shell, I stuffed the apertures of several occupied shells with soil firmly, so that the snails were out of sight and reach. The external appearance of one of these shells was to a human observer precisely like that of a stuffed one, unless it was held up to the light. Then the central turns of the unoccupied shell into which it was impossible to force the soil appeared lighter than in the shells containing snails. The shells with apertures closed with dirt were placed,

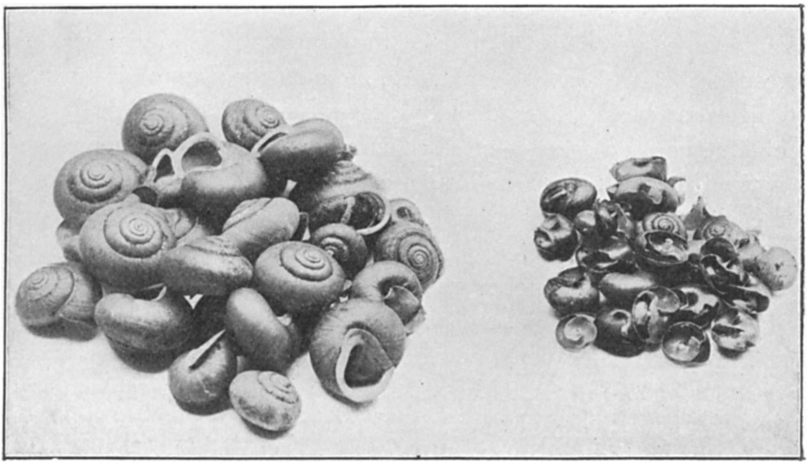

FIG. 5.— The empty shells taken from a single underground storage chamber of *Blarina brevicauda*. The shells on the left were entire: those on the right broken, being mostly immature shells of the same species as those on the left.

along with stuffed and empty shells, at several burrows. The occupied shells were again removed, to the exclusion of the others.

Sight.— Blarina has not been accredited with acute vision, the principal function of its eyes being, as Merriam (1886, p. 165) has supposed, to distinguish light from shadow. To determine this point at first hand, various tests were made on the shrew in the laboratory. Objects varying in size from a lead pencil to a book were waved before the shrew, first at a distance of a foot or more. No notice was taken of them. The distance was gradually shortened until the objects almost touched the shrew's vibrissae, but still the animal was not disturbed. Once when a cigar box was thrust violently toward the shrew, the latter shrank back and immediately turned to face the object. Thinking that the response might have been due to air currents, I moved various objects, as cards, boxes, or books, toward or past the shrew in an oblique position so as to produce currents. The shrew invariably noticed these although its head was sometimes turned away from the object. I then blew lightly upon the animal and it turned toward me and chattered vehemently. I have concluded that, in the above case where notice was taken of the cigar box, the response was due to air currents, and that the box had not been seen.

The above experiments were all performed with the cage between the moving objects and the window. When similar movements were made on the opposite side of the cage so as to throw a shadow over the shrew, the animal was at once disturbed. If a large object, as a book, were used to cast the shadow, the shrew frequently hurried into one of its burrows. Sight, then, can hardly serve to distinguish occupied from empty or stuffed snail shells in cases where a human observer could not discern a difference. The remaining possible means of distinguishing them is by their odor.

Smell.— When mice or beef were placed in the cage the shrew almost invariably came out of its burrows in a short time. It rarely did so when the lid was merely raised and lowered, or when other objects, as the water dish, were put in. In the case of the mouse, the response may have been due either to the trembling of the soil as the mouse ran about, or to the odor of the mouse; but with the beef, the disturbance of the ground was eliminated. When the shrew was above ground, it was always going about with its nose slightly elevated and its nostrils dilating and contracting rapidly in unison with movements of the sides of the body, as if sniffing the air. It is further noted (Table I) that only 7 of the 25 snails killed in formalin were ever moved from their places at the burrows in the field. I have concluded from all these observations that the distinction between empty and occupied shells is due chiefly to the odor of the snail. Possibly weight is another factor, for although the experiments showed that weight was not effective apart from odor, no experiments were performed with odor apart from weight.

Hearing.— It has been pointed out by both Merriam (1886, p. 165) and Kennicott (1857, p. 95) that the hearing of the shrew is acute. This was not at once apparent from the shrew that had been for some time in confinement. It was oblivious to sounds that were often repeated. It took no notice of footsteps, and conversation did not disturb it. Even the slamming of the door did not at the last appear to be perceived, but slight sounds that I produced for the first time made the shrew start. Plucking a taut string within a foot of the shrew produced this result. A shrill whistle caused it to run into the corner of its cage, though I was careful not to blow upon it. It started violently when a strip of metal was drawn across the lip of a tin can near the cage. Each of these noises when repeated a number of times at various intervals ceased to produce any effect, even when several days had elapsed since last producing them. The flutter of wings of a pigeon kept in the same vivarium, on the other hand, always sent the shrew scurrying into its burrows. I observed this more than twenty times, at intervals throughout the five weeks of the shrew's captivity, and the last flutter produced as much disturbance as the first. This particular sound must have been heard hundreds of times during that period, yet even at the last could not be heard with equanimity by the shrew.

Effect of Light and Heat.— Sufficient evidence has been offered that most of the shrew's work on snails is done at night. Eight of eleven voles and mice put into the cage of the shrew were killed at night. Most of the food which was small enough was dragged into the burrows to be eaten. In my field work I twice saw a shrew come momentarily to the surface, once in March and once in April. Both days were rather cool, though the sun was shining brightly. Still more conclusive, at least in regard to heat, was the behavior of the shrew when brought out to be photographed in a dish lined with white paper. The animal was exposed to direct sunlight when the temperature was about 30° C. It tried at every point to get under the paper lining of the dish, while its breathing rapidly increased. After some 8 minutes of exposure it was evidently overcome by heat, and after dancing wildly about a short time on all fours, lay motionless. Long continued bathing with cold water was necessary to restore it. It is evident that times of daylight and even ordinary summer heat are not selected by the shrew for its greatest activity. On the other hand, even if there were no direct evidence of daylight activity, the capture of shrews by hawks (Fisher, 1893) shows that the animals occasionally come out upon the surface by day.

Summary of Principal Results.

1. *Blarina brevicauda* preys upon various snails of the genus Polygyra, at least in winter.
2. These snails are hoarded, and are in general moved to the surface of the ground as the temperature falls and into the burrows as it rises.
3. Empty shells which are brought to the surface are not moved back into the burrows. The basis of distinction between empty and occupied shells is the odor of the snail, or possibly the odor combined with the weight.
4. Empty shells not left at the surface are stored about the nests, along the burrows, or in special chambers.
5. Other principal foods are voles, mice, insects, and earthworms. Vegetable foods, except nuts, are not employed.
6. The burrows of *Blarina brevicauda* are similar to those of *Microtus pennsylvanicus*, but may be distinguished by the following features:

a. The runs of Blarina, when underground, open to the surface at points more than 1 meter apart; those of Microtus have openings less than 1 meter apart. Burrows of Blarina often extend as deep as 40 cm. into the soil; those of Microtus rarely more than 15 cm.

b. The nests of Blarina are always underground; those of Microtus are more usually at the surface.

c. Blarina uses all its nesting materials unaltered; Microtus shreds or tears coarse material.

d. The excrement of Blarina is greenish black, coiled spindle-shaped, about 25 mm. long; that of Microtus is black or brown, spindle-shaped, 5 to 8 mm. long.

7. The smell, hearing, and tactile sense of Blarina are acute; its sight serves merely to distinguish light from shadow.

DISCUSSION.

The short-tailed shrew is easily recognized. It differs from other shrews by its large size, having a total length of 120–124 mm., by its short tail (23 mm.), and relatively small feet (hind foot, 15 mm.). From the common mole and Brewer's mole, it is distinguished by its smaller size, and by the absence of digging forefeet; from the starnosed mole it is further separable by the absence of tentacles around the snout.

In the field, the work of Blarina is readily distinguishable from that of either the common or starnosed mole by the smaller burrows, and the absence of humps of earth which are so characteristically heaped up by both moles. A further distinction is the ridge of earth over the burrows of the moles, especially the common mole. Blarina does not make such a ridge, at least in soft ground.

It has been noted that the runs used by Blarina at the surface of the ground are precisely like those of Microtus but that the burrows as a whole differ in several respects. The most interesting of these differences concerns the material of which the nests are composed. Shredding or tearing it into pieces would perhaps make the nest more comfortable and the shrew is fully capable of thus altering its material. But the shrew is carnivorous and Microtus is a rodent. To the latter, with its gnawing incisors, accustomed to dividing and tearing roots of grasses and the bark of trees, the shredding of nesting material is a natural process.

The collecting of empty shells around the nest of the shrew seems significant in relation to the origin of the nesting habit. One nest which I have described was made entirely of the hair of the vole, rejected parts of its food. Microtus nests are commonly made of the husks, leaves, and silk of the corn, or of the chaff and leaves of the wheat which it devours. It is easy to conceive that in this way the nesting habit of the shrews also originated. If this be true, the use of grass, leaves, and sedge, now so common among the shrews, must be a secondary modification, since these articles are not rejected food materials.

The fact that in the laboratory the shrew did not make any defined runs at the surface, suggests that it may not make any in the field. If this is true, the runs which it occupies were probably made by Microtus. They may have been entered in pursuit of game, and when the original owners were captured, their burrows were appropriated. The finding of broken snail shells in Microtus nests seems to support this view, since Microtus does not eat snails. The shells must have been carried thither on a foraging expedition, and devoured in the nest of the vole. To what extent the runs used by Blarina have been appropriated by it has not been determined.

Many of the shells found around the nests of Blarina, in underground chambers, and in the burrows, were shown by the numbers painted upon them to be those which were previously heaped at the surface. The snails, therefore, were being hoarded, and used gradually. Bachman (1837, p. 370) mentions that beetles are hoarded by shrews of the genus Sorex, and Merriam (1886, p. 169) thinks it probable that Blarina stores food. Dahl (1891) has found masses of earthworms, having their anterior segments injured, in the burrows of the European mole; but Adams (1903, p. 14) thinks they merely fell in and could not get out,— he does not explain the injury of the anterior segments. There is no mention of hoarding among shrews on as large a scale as this of the snails seems to be. It has been noted that the snails were carried out on top of the ground in considerable numbers when the temperature fell markedly, and were taken back in equally large numbers when there was a marked rise in temperature. The snails seem to be kept in the coldest place available. In cold weather this is above ground; in warm weather, in the burrows. Though the temperature in February and March never rose high enough to render the snails active, yet some of the snails at the burrows referred to in Table II were still at the surface early in April when it was warm enough for them to crawl. This may have been due to the fact that my first shrew was captured at this set of burrows, so that only one shrew was left to devour the snails originally intended for two. Bodies of Microtus were hoarded but were not transferred to the surface. This again indicates that the cold storage serves to keep the snails immobile rather than to prevent decomposition.

Too little has heretofore been known of the short-tailed shrew to make an estimate of its economic importance practicable. Stomach examinations are almost wanting, my own work including but two. However, from data concerning the quantities of food in laboratory and field, I have attempted an estimate of the economic importance of Blarina.

Three principal elements determine the economic value of a species, namely its range, its abundance, and the character and quantity of its food. Of the range of Blarina, Rhoads says (1903, p. 192): "Atlantic Ocean to Nebraska and Manitoba; Quebec to Virginia." This is practically the northeastern quarter of the United States. Of its abundance, the same author says (p. 193): "This species stands preeminent above all others of our mammals in its combined abundance and universality of distribution in all conceivable situations. Not a place have I trapped over in the two states but what it was among the first species to be caught. It is found in our deepest, coldest mountain ravines, on the stormy, barren mountain top, in the banks and valleys of low tidewater streams and maritime marshes, and delights in roving from the cool sphagnum bogs of the N. J. cedar swamps where the temperature may be below 60° to the hot sand barrens of the adjoining fields with a mid-day heat of 110.° Forest and plain, sand and clay, barren or fruitful field, back woods or door yard, heat and cold, wet and dry, day and night, have common charms for this cosmopolite." It is difficult to conceive of the shrew in some of these situations after having observed its almost futile attempts to burrow in heavy, sandy soil that was not even compacted. Yet numerous records attest its presence in these situations.

Montgomery (1899, p. 572) has used the number of skulls of different mammals found in the pellets of owls to determine the relative abundance of the animals. Shrews necessarily came far down the list, because few were captured; and he found that *Blarina parva* is more abundant than *B. brevicauda.* It seems to me that the small number captured is due to the fact that they are underground most of the time, rather than to their rarity. From my own observations, assuming that a pair was present at each nest that was being used, as I found to be the case in two instances, there were at least two pairs to the acre over the region studied. This number should be easily maintained for, according to Rhoads (1903, p. 195), they produce four to six young at a litter, and breed the year round.

The quantity of food eaten in a month has been estimated as follows: From Table III was computed the quantity of each item which would have been consumed in a month had that article alone been furnished. For example, one month's rations of voles alone would be 20; of house mice, 30; of adult May beetles, 450; and so on. It has already been stated that 130 snails were eaten by one shrew between Mar. 1 and Apr. 31. However, since the moving of the snails by the shrew had practically ceased by Apr. 7, it seems probable that the snails were eaten in a little over one month. Moreover such other foods as insects, earthworms, and voles were available at the same time, so that the snail diet was not the total. It seems reasonable to assume that 120 snails alone would make one month's rations, since that is more nearly the equivalent of 20 voles.

The distribution of the dietary among the different articles is largely a matter of judgment, and in Table IV the quantities are based on the relative abundance of the various items in the swamp region studied. For example, voles were abundant, and have been allowed to constitute 40% of the diet. Earthworms, on the other hand, were comparatively rare in the peat of the swamp, and have been allowed but 5%. The table of course represents only a sort of average for the year. Snails are evidently eaten in much greater numbers during several months of the winter, when the insect diet is necessarily limited. The snail diet is probably less in upland situations, though Charles A. Shull, of Kentucky University, tells me he has found the characteristic heaps of snail shells, all *Polygyra thyroides,* about the openings of small burrows in high land near Lexington, Ky. This was probably the work of Blarina. In other situations than the peaty swamp, the earthworm diet is probably greater than I have estimated. In proportion as other foods not here included are employed, the quantities in the table will be diminished.

TABLE IV. Showing estimated quantities of various staple foods devoured by a single *Blarina brevicauda* in one month.

Article of Food.	Estimated number eaten.	Per cent. of total rations.
Meadow voles (or equivalent in mice)	8	40
Adult insects (of the size of Lachnosterna)	90	20
Insect larvae (of the size of Lachnosterna)	78	20
Earthworms (4 cm. long in contracted condition)	53	5
Snails	18	15

Estimating the number of shrews as I have done at four per acre, it appears that the number of meadow voles devoured by them on a farm of 100 acres in a year is 100 × 4 × 12 × 8 =38400. Since this number can scarcely be supplied, the capacity of the shrews for keeping the voles in check is not strained. Where this quantity of voles can not be found, either other foods must be eaten in equivalent amounts, or the shrew is capable of subsisting on shorter rations, or the estimated four shrews per acre can not exist. Farmers should take note of the economic value of Blarina. In their zeal to rid their premises of noxious animals, they sometimes kill indiscriminately anything that looks like a mouse. One of these animals evidently kills many more voles in a year than the farmer himself. The shrew even compares favorably, from the economic standpoint, with the common owls. Montgomery (1899) examined the pellets of four long-eared owls for a period of two months, and found that these birds had devoured 347 small mammals, mostly Microtus. This is an average of 43 per month for each owl. Blarina devours 20 voles per month, or an equivalent in insects, most of which are even more destructive than the voles.

With abundance of food, it might be expected that the race of short-tailed shrews would become very numerous. But other forces are at work maintaining the balance of nature. The investigations of Fisher (1893) show that six species of hawk and six species of owl capture the short-tailed shrew. Two other species of owl capture shrews but the species of shrew is not stated. Montgomery (1899) found the skulls of shrews in the pellets of the long-eared and the short-eared owl. The number of shrews taken, however, is relatively small. For example, Fisher (1893, p. 53) found in 562 stomachs of the red-tailed hawk 45 specimens of shrews. Of these one third were short-tailed shrews, taken in 10 individual stomachs. In 39 stomachs of the barn owl (p. 139) 5 specimens of shrews were found, among which was Blarina. Montgomery (1899, p. 566–567) found that out of 347 skulls of mammals taken from the pellets of the long-eared owl, only one belonged to Blarina. These figures show that the item of shrews does not count very heavily against the hawks and owls in estimating the economic value of these birds.

The subject of bird enemies of the shrew recalls the disturbance produced in the laboratory by the fluttering of the pigeon's wings. The sound was probably recognized as a familiar one by the shrew. This accounts for the fact that the animal never became oblivious to this particular sound.

Surface (1906, pp. 155, 160, 189, 197) has found shrews in the stomachs of four species of snake, though in small numbers. In at least one case he was able to identify the specimen as Blarina. Rhoads (1903) and Stone and Cram (1902) state that small mammals are captured by foxes, minks, weasels, and skunks. In several instances they mention shrews among the number, but in no case is specific mention made of *Blarina brevicauda.* Dickerson (1907, p. 356) records that three specimens of *Blarina brevicauda* were found dead in the fallen nest of a red squirrel. She believed them to have been killed and stored there by the white-footed mouse. This mouse is well known to utilize deserted nests, among others that of the red squirrel, but whether it kills shrews is doubtful. It appears to me more probable that the shrews had been killed by larger beasts of prey and rejected, possibly on account of their odor (Rhoads, 1903, p. 193; Stone and Cram, 1902, p. 182), and had then been picked up by the whitefooted mouse. This mouse is said by Stone and Cram (1902, p. 132) to glean after other hunters.

From bird enemies the shrew can escape to its burrows. From those enemies that can pursue it in its burrows, some other means of escape must be employed; perhaps it pushes out into the loose soil. The instance of the obliquely descending burrow at one nest suggests the "bolt run" by which the European mole is said to escape when its fortress is attacked (Adams, 1903, p. 13). This burrow, however, was probably not a back door escape, since it ended blindly and the shrew did not enter it at this time of attack.

The short-tailed shrew is so well protected from its enemies that no animals appear to depend upon it for food. It is abundant and widely distributed. In security it devours such quantities of voles and insects that its economic importance is considerable; and since, unlike the other common shrew, *Sorex personatus*, it is almost exclusively carnivorous, there is little to detract from its economic value.

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